PLUTONIUM THERMAL TREATMENT FURNACE TRANSFER SYSTEM

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ABSTRACT

An equipment modification for reducing the time required to thermally stabilize plutonium residues at the Hanford Plutonium Finishing Plant (PFP) has been developed. Stabilization of these residues is performed in box-like muffle furnaces, where the heat up and cool down cycles constitutes the majority of the process time. Reducing the overall cycle time could accelerate the completion of residue stabilization, achieving cost savings and meeting aggressive schedules to place all residues into secure long-term storage.

Pacific Northwest National Laboratory (PNNL) and Fluor Hanford, Inc. (FH) personnel teamed up to develop a concept of a "hot box" that could be placed between two existing furnaces and eliminate most of the heat up and cool down portions of the time cycle. PNNL researchers designed and constructed a fully functional prototype of the furnace transfer system in a short 5-month period. Calculations have shown the overall processing time for the residues can be reduced by a factor of two to five (or more) depending on the type of residue and the length of shift operations. Implementation of the furnace transfer system is projected to occur in late FY 2002 or early FY 2003.

INTRODUCTION

At the Hanford Plutonium Finishing Plant (PFP), plutonium residues associated with previous processing campaigns are being removed from storage vaults and thermally stabilized in preparation for disposal. The residues are placed into welded stainless steel containers to facilitate long-term storage and eventual transport to the final disposal processing location. The stabilization is performed in muffle furnaces, where the heat up and cool down cycles constitutes the majority of the process time through this stage. Typically, a 16-hour cycle is required to heat up, stabilize, and cool down a single furnace load of material. Reducing the overall cycle time, principally in the heat up and cool down cycles, could greatly accelerate the completion of residue stabilization. Speeding residue stabilization will help the FH meet aggressive cleanup schedules and reduce the cost of the PFP cleanup.

Several gloveboxes located at the PFP contain muffle furnaces used for thermal stabilization. A team of PNNL and FH staff members developed a concept for a "hot box" that could be placed between two existing furnaces in a one of these gloveboxes. Elimination or reduction of the heat up cycles could be accomplished if the materials to be treated could be placed directly in a hot furnace. Likewise, if the hot, thermally stabilized materials could be removed from the furnace while hot would eliminate or reduce the cool down cycle.

The concept was simple; build a loading chamber that would shuttle "boats" of Pu-bearing residues into and out of the furnaces followed by transfer to a chamber where the boats could cool to room temperature. While the concept itself was simple, implementation presented design and fabrication challenges that had to be solved before a successful system could be constructed. Specific safety, security, and criticality specifications had to be considered, as well as simplicity of design for installation, operation and maintenance. The final design provided a system that was easy to operate, mechanically simple, and that met all applicable requirements. Since simple equipment that works in concert with the current furnaces was selected, no major modifications are needed that would require additional safety analyses and documentation, and/or capital project initiation.

CURRENT TREATMENT APPROACH

Thermal stabilization of Pu-bearing residues began at the PFP in 1997, using two industrial muffle furnaces with programmable controllers to process individual batches of residue material. Airflow through the furnace and a cover gas inlet are provided, but maximum flow is limited to prevent excessive entrainment of particulates.

The residues are placed into a material boat that can contain up to about 2 liters per furnace load. A boat is manually placed into a cool furnace, the door shut, and the thermal stabilization cycle initiated. The cycle includes a controlled heat up to prevent damage to furnace components, requiring about six hours to reach the desired 1000°C stabilization temperature. The 1000°C temperature is held for two hours to meet the requirements of the long-term plutonium storage standard, DOE-STD-3013-2000, *Stabilization, Packaging, and Storage of Plutonium-Bearing Materials*. Then a cool down cycle is initiated, taking approximately eight hours to reach a temperature where the process operators can open the furnace door and allow a final cooling of the boat with the door open.

The 16-hour furnace time cycle for each charge is the time limiting step in the overall stabilization process. In an attempt to provide for more capacity, similar furnaces have been installed in another glovebox. Still more furnaces with expanded charge capacity have been installed in a second facility associated with the long-term storage vaults. However, it would be advantageous to provide reduced time cycles and accelerate throughput through the existing furnaces. This would provide the potential to deal with compressed schedules resulting from unforeseen shutdowns, and the ability to meet milestones to place all residues in a stabilized condition into 3013 containers.

FUNCTIONS AND REQUIREMENTS FOR CHANGING THE APPROACH

Considerable investment has been made in the existing muffle furnaces. Operational procedures are in place, the staffs are trained and familiar with the operations, and stabilization is progressing. Thus, while a continuously fed, multiple heat-zone furnace might be envisioned as a potential replacement for the muffle furnaces, such an idea becomes impractical in light of these other factors. Any operational improvements would have to focus on improving throughput of the existing furnaces.

The idea of developing a shuttle-system for moving material boats into and out of the furnaces was an easy step for the design team. The next step was to gather the physical and operational constraints that exist in the facility to insure a successful design.

Thermal Considerations

The most extreme case considered by the design team involved operating two muffle furnaces in a glovebox continuously at 1000°C while being able to move material boats in and out while at temperature. Continuous operation of the furnaces would put a more waste heat in the glovebox than the current stabilization strategy. The gloveboxes have thermal protection alarms and fire prevention systems that limit the operating temperature. Administrative controls also limit the internal temperature of the gloveboxes for worker safety. Disipation of waste heat and protection of the operators and glovebox became important factors to the design.

Transporting material boats into and out of hot furnaces also created some problems related to materials selection. The 1000°C operating temperature is high enough that corrosion of metals and thermal shock resistance of ceramic materials becomes a concern. Further, any water adsorbed on surfaces of any cold materials placed into such a high temperature environment can create problems due to rapid steam generation. The final design would have to accommodate for these problems as well.

Operational Considerations

Radiological glovebox operations can be strenuous and difficult for operators. The ability to move equipment in and out is severely limited by the size of entry ports, radiological conditions, and the confined space of a glovebox crowded with other equipment. The first glovebox at PFP proposed for use has two reasonable methods of entry. One method is to use a bag-in/bag-out port that is circular and measures about 30 cm in diameter. The second method is a conveyor belt system mounted at one end of the glovebox that is used for transferring material boats into and out of glovebox. The conveyor system is contained in a tubular box having a cross section of about 30 cm x 30 cm. The design team had to be able to fit all parts and pieces of any new equipment through those two openings.

Once the parts are inside the glovebox, operators with gloved hands must assemble them. Simplicity of the design is essential so operators can handle the parts, any fasteners, connectors, and tools with ease and without creating operator fatigue.

Finally, any operational controls must be easy to operate with gloved hands. Simple in-out, push-pull type controls were deemed best. Mechanized controls would be desirable, but these were thought to be prone to failure, add additional complexity, and add additional cost to the equipment.

The existing ventilation provided to the glovebox is provided through a rectangular vent at the top of the glovebox. Air enters the glovebox through the conveyor belt system. It was desired to add not new ventilation capacity the equipment would have to function within the pressure head limitations of the existing facility air handling system. The nominal airflow through the glovebox is 70 scfm at ambient temperature. Most of the waste heat from the muffle furnaces must be dissipated to the air that is swept away by the ventilation system. Since no new ventilation capacity would be added, the operation of the system could be constrained by the ability of the ventilation system to remove heat.

CONCEPTUAL DESIGN

The furnace transfer system conceptual design had to satisfy the functions and requirements that had been identified. This pointed out the need for a thermal modeling of the system and the glovebox environment. The design team began to develop the concept for the system and used 1- and 3-dimensional thermal modeling to assist in finalizing the design and to support the selection of materials for use in constructing the system.

The conceptual design that evolved was drafted using a mechanical design software package. The software allowed rendering of the design in three dimensions. Fabrication sketches could be taken directly from the three dimensional representation, which proved useful to the craftsmen who were responsible for fabrication the system. One view of the finalized conceptual design is shown in Figure 1.

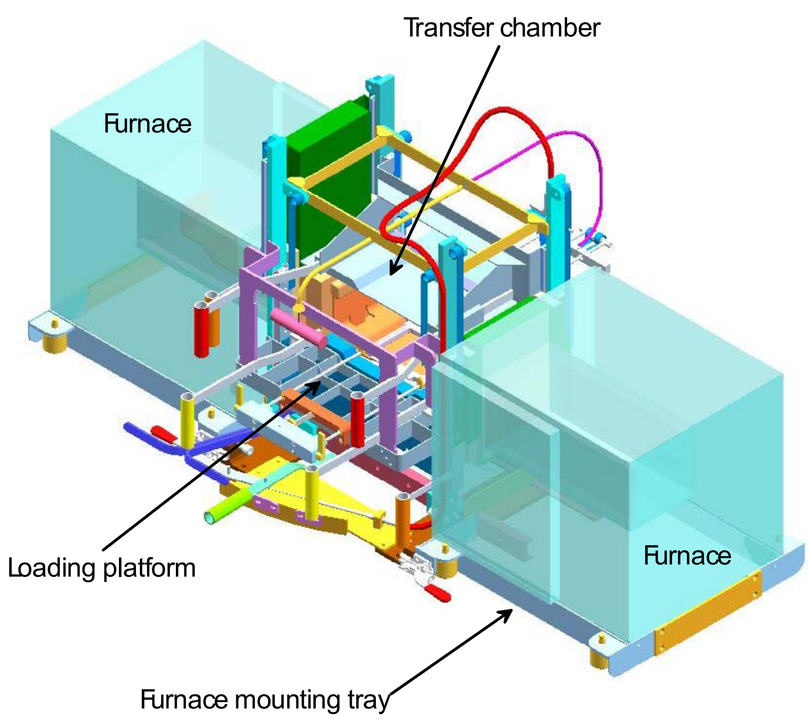

Fig. 1. Illustration of the furnace transfer system concept.

This design has a material transfer chamber that allows loading of the furnaces while isolating operators and the glovebox environment from excessive heat loads. Two material boat shuttles located in the transfer chamber allow alternate charging of the two furnaces. The cooling chamber is used to rapidly cool the thermally treated materials. All operations are performed from one side of the system, with all material boats being loaded and unloaded from the loading platform.

The thermal analyses were performed using this design model and a material boat holding 2 kg PuO_2 heated to 1000°C as a heat source in addition to the two operating muffle furnaces. The results of the thermal analyses were promising. The models showed the system should not heat the glovebox about 50°C which is lower than the 65°C administrative control point for the glovebox. The waste heat from a fully loaded boat was shown to cool from 1000°C to ambient glovebox conditions in about two hours. Thus, the existing ventilation system was adequate to protect the operators and glovebox from excessive temperatures. The thermal gradients indicated that most of the system could be built using simple carbon steel and/or stainless steel. Only the material boat shuttles would have to be fabricated from a high-temperature nickel alloy to resist corrosion and loss of strength at temperature. Once the thermal calculations were complete, the conceptual design was finalized.

FINAL DESIGN

The final design of the furnace transfer system has four stages:

- The loading platform, where process material boats are staged in and out of the system
- The transfer chamber/loading station
- Two furnaces for the heating stages
- A cooling chamber.

The heart of the system is a pair of loader cars which each incorporates a shelf of high-temperature alloy, a ceramic furnace door, and a chassis with precision rollers running on a pair of rails. The loader chassis have handles with detents with which the operator can move and position the units. The loaders alternate position between the central transfer chamber/loading station and their respective furnaces.

The furnaces are positively located with respect to the rails and mounted on ball casters so they can be moved easily for servicing. They face each other with the furnace transfer system between them. The furnace transfer system also has:

- An inserter/retractor mechanism to move material process boats onto and off of the loaders
- Doors to close the furnaces while a loader is retracted to transfer boats
- A transfer case and facilitate transfer from the cooling chamber to the loading platform.
- Compartment doors to isolate the stages.

The furnace transfer system is operated using simple push-pull mechanical devices to keep operations simple, robust, and easy to repair in a remote environment should repair ever be necessary. The design concept protects the furnaces from the stresses of thermal cycling and repeated impacts and abrasion of linings from hand loading and unloading in difficult conditions.

Heating element replacement, currently required on a frequent basis, should be reduced considerably. The final design was consistent with the illustration shown in Figure 1.

FABRICATION

Once the design was finalized, the fabrication sketches could be taken from the design using the mechanical design software. The sketches could be rendered in isometric views and three-dimensional shaded images. The software contains features that allow the three-dimensional views to be rotated, allowing one to "view" the part from many different angles. All the fabrication sketches were transferred to a computer server that could be accessed via other computers in the fabrication shops. In addition to the paper copy fabrication sketches, the craftsmen could look up parts on the computer to learn more about each piece as they made them. The system went from final design to fabrication in a single step. This eliminated the need for a formal design review activity that saved time and funds. An example of some of the fabricated parts and their design drawings is shown in Figure 2.

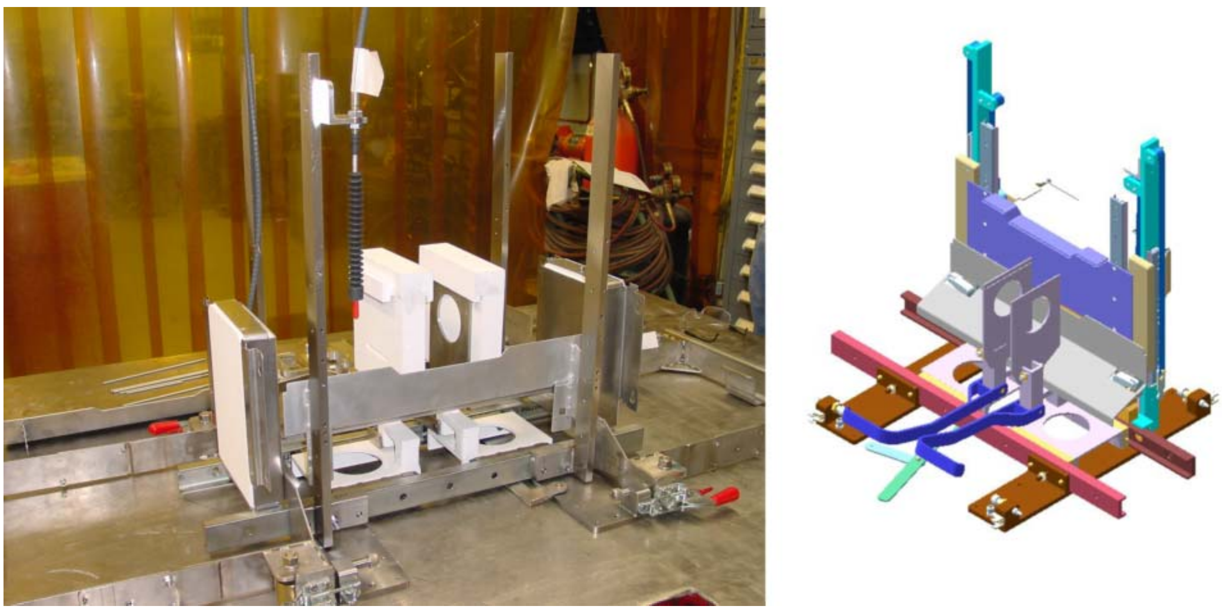

Fig. 2. Picture on left shows some of the furnace transfer system components during the fabrication process. Illustration on the right shows some of the same parts as designed using the mechanical design software.

Once all the parts were assembled, the system was ready for bench-top assembly and testing. Modest amounts of rework were anticipated, but the amount of rework that was actually required was less than expected. The completed system is shown in Figure 3.

ASSEMBLY AND TESTING

Before placement in the glovebox, some the parts for the furnace transfer system are partly assembled in subassemblies. The subassemblies minimize the amount of work that must be done

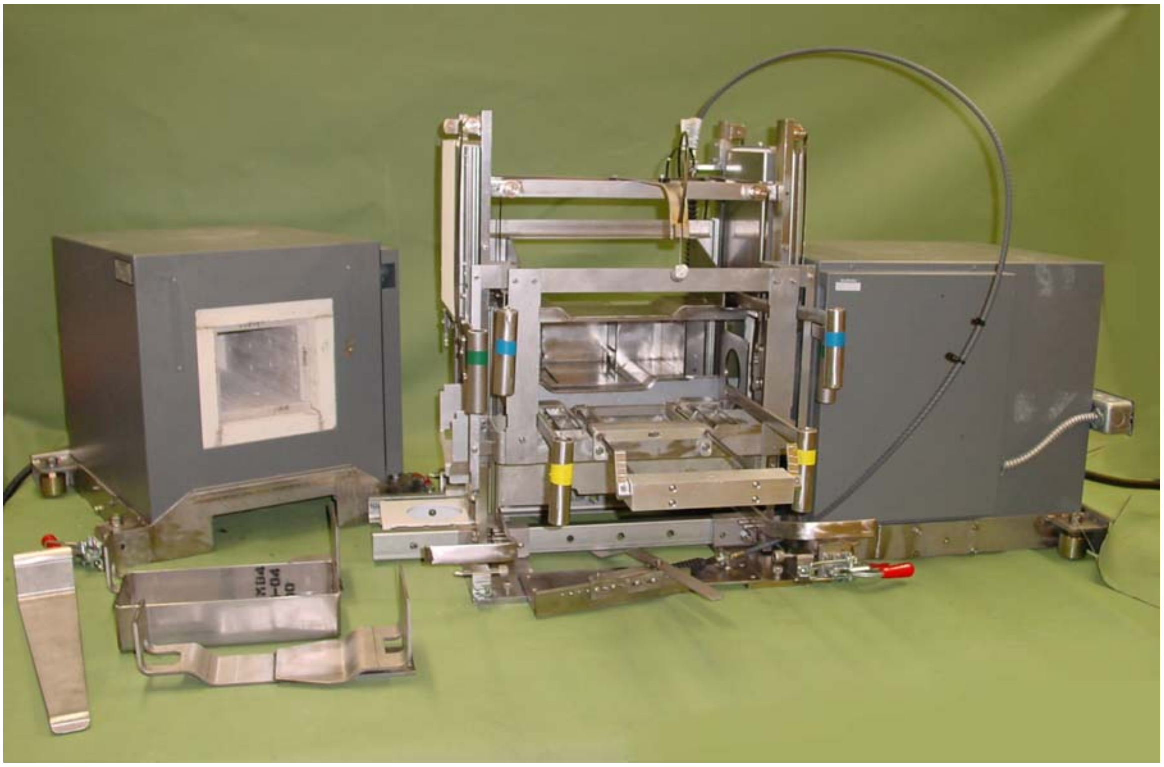

Fig. 3. Completed furnace transfer system. A material boat and high-temperature alloy "shelf" is shown in the lower left of the figure. The furnaces can be rolled up to the system and are held in place by simple lever-clamps.

inside the glovebox. All of the individual parts and subassemblies can be placed into the glovebox using the bag-in/bag-out port or via the conveyor belt system. Care was taken to assure all necessary bolts had allen heads and the lead threads removed from the first 3-4 mm of the bolts. This allows the operators to use T-handled allen key wrenches that are easier to handle with gloved hands and the "leads" on the screws allow for easier threading of the bolts.

To test the ease of assembly, the entire system was assembled in a glove box mockup. An exact plywood replica of the glovebox at PFP where this system may be first used was fabricated. The system was "bagged-in" and assembled in a single eight-hour shift by two PNNL staff members. The actual time to assemble the system in the radiological glovebox at PFP will take several days longer due to the complications of working in a radiation environment. The glovebox mockup can serve as a training tool if desired by the PFP operators. An assembly manual has also been prepared to support the assembly operations.

Next the furnaces were energized while the system was in the plywood glovebox mockup. The thermal analyses indicated the assembly would not heat the surrounding glovebox environment more than about 50°C. The furnaces were brought to temperature (1000°C) and allowed to sit for several hours. Boats full of cerium oxide (CeO_2, a nonradioactive stand-in for PuO_2) at ambient temperature were loaded into the furnaces (while the furnaces were at elevated temperature). The boats took about one hour to reach equilibrium temperature with the furnace.

During operation temperatures were taken at various points on and around the system. The air in the glovebox was static so there was no airflow to help cool the system. The design calculations were confirmed; nowhere did temperatures exceed those indicated by the design. Once the heating was complete, the boats were placed one at a time into the cooling chamber. The cool down time was measured to be about two hours.

Next the system was disassembled and inspected for potential thermal shock failures. None were found. The system was then operated for one week for continued testing. No failures of any parts were observed. The system met the required functions and requirements and could be installed at the PFP. A picture of the system installed in the plywood glovebox mockup is shown in Figure 4.

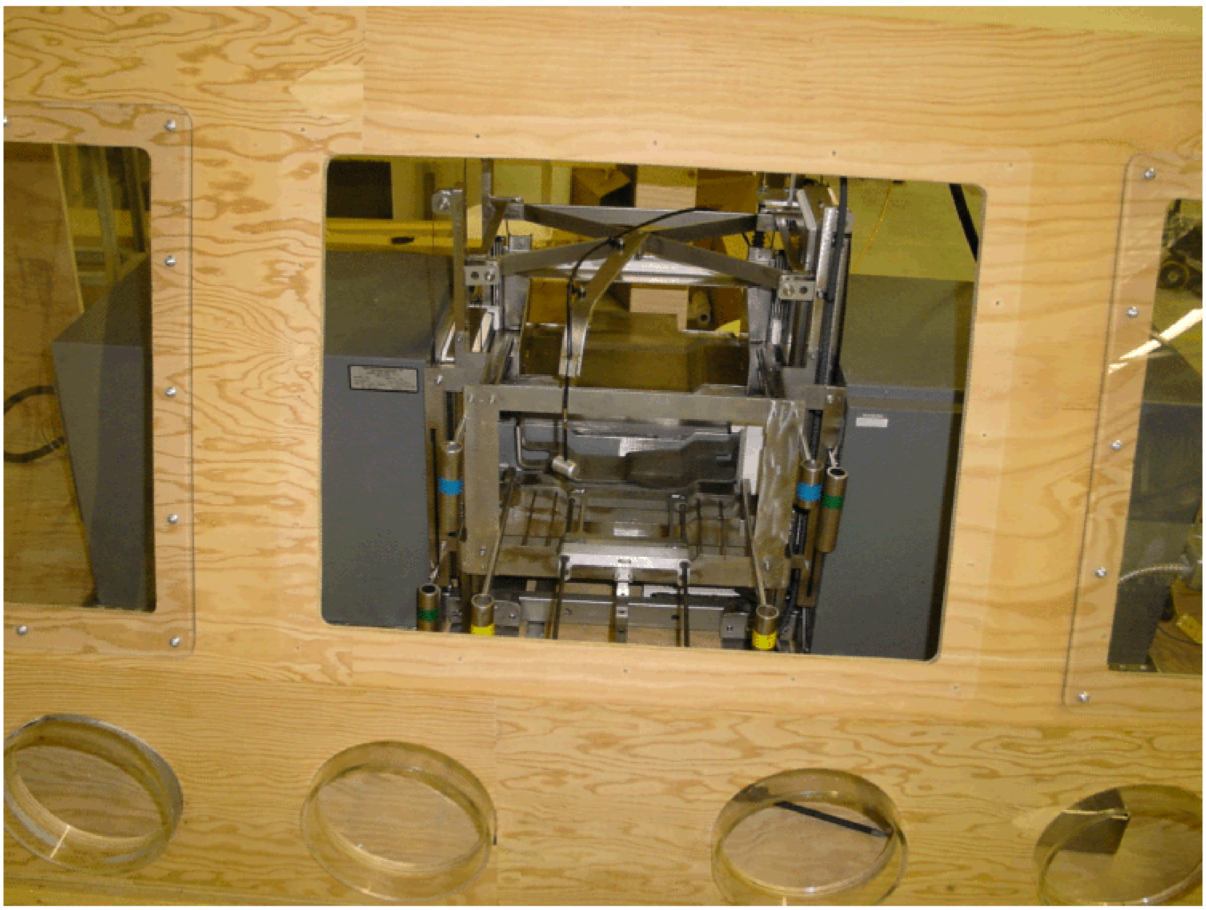

Fig. 4. The furnace transfer system installed in the plywood glovebox mockup. The system is installed and located, as it would be in the radiological glovebox at the PFP.

CONCLUSIONS

A system for increasing the material throughput of two plutonium thermal stabilization furnaces has been designed and fabricated. The system allows material to be loaded into the furnaces at ambient temperatures and unloaded at high temperatures. The heat-up and cool-down cycles for materials to be stabilized in these furnaces can be reduced by about 11 hours. The timesavings for thermal stabilization of Pu-bearing materials in these furnaces can be greatly reduced by using the furnace transfer system.

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